AN-105

Advantages of PhotoVoltaic Relays in Multiplexers

By Allen Garfein

Introduction

While modern instrumentation system designs are almost entirely solid-state, an exception to this dominance has been the electro-mechanical relay (EMR) used in analog multiplexer inputs. Until recently, the critical performance characteristics of these switches could be met only by traditional electromechanical relays. There was no choice in turn to accepting the performance limitations of these EMRs.

All Solid State Multiplexers

The use of International Rectifier microelectronic power IC PhotoVoltaic Relays (PVRs) in multiplexers can greatly increase life and reliability, allow systems to operate at higher scanning rates, eliminate measurement errors from thermally generated offset voltages, reduce operating power, provide greater mechanical ruggedness, and decrease instrument board sizes. PVR devices can be widely applied in multiplexing designs as replacements for reed relays, stepper switches, crossbar switches and monolithic CMOS integrated circuits. A typical multiplexer schematic is shown in Figure 1.

Figure 2 is a pair of photographs showing a recently redesigned MUX card using International Rectifier PVRs in comparison with an older design using EMRs.

In addition to the obvious space savings, International Rectifier's PVR offers numerous electrical performance advantages. These advantages of the solid state PVR are now possible because of recent advances in MOSFET technology which allow the nearly ideal open/closed contacts of electro-mechanical switches to be essentially duplicated by semiconductor structures.

A Better MUX Switch: PVR

The numerous solid state advantages of the PVR relative to the traditional EMR allow the instrumentation designer to design more reliable equipment. In addition, by capitalizing on the unique PVR features, the innovative designer can create higher performance systems of smaller size. The major PVR advantages to MUX designers include the following:

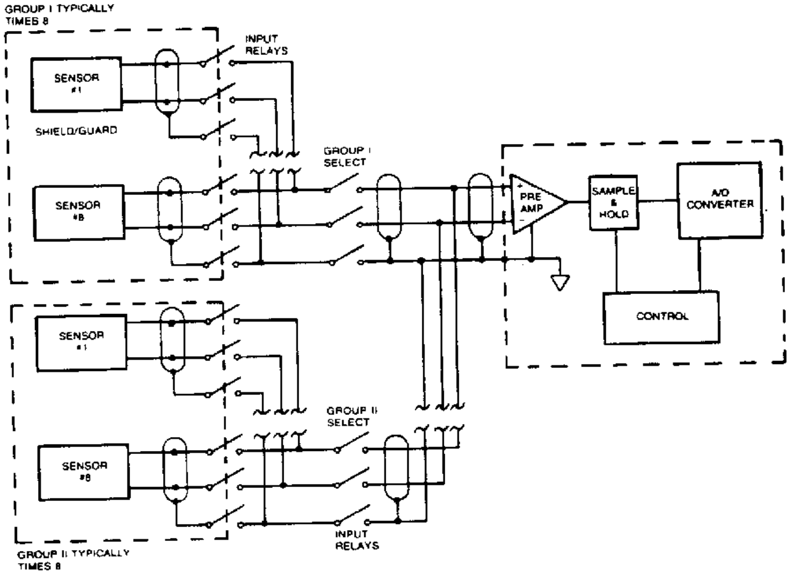
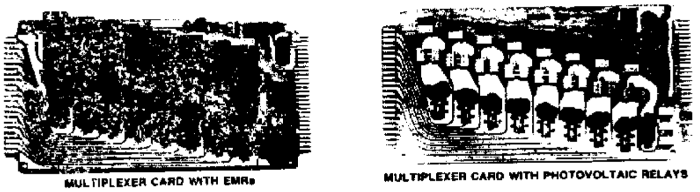


Figure 1. Typical Multiplexer System



MULTIPLEXER CARD WITH EMRs

MULTIPLEXER CARD WITH PHOTOVOLTAIC RELAYS

Figure 2. Comparison of Electromechanical and PhotoVoltaic MUX Board

1. ***Life*** — PVR devices have a demonstrated switching life of 10^{10} operations (see application note AN-106) when switching signals as high as 50 volts at 20 milliamperes (1 watt). The best reed relay EMRs achieve life of only 10^9 operations at much lower power switching levels and after burn-in screening

2. ***Low-Thermal*** — PVRs easily achieve thermal offset voltages below 0.2 microvolts. This low spurious signal level is possible because the simple output structure produces minimal thermal junctions. Furthermore, the actuation power which is as low as 3 milliwatts, versus typically 50 milliwatts for a reed relay, produces negligible heating.

3. ***Speed*** — Full on-off settling times without any noise inducing bounce can be less than 50 microseconds, approximately 20 times faster than EMRs. This speed, plus the extended life, makes much higher scanning rates practical. "Break" before "make" performance is provided by a fast turn-off circuit integrated into the power output stage.

4. ***Input Drive*** — Control can be achieved with as low as 3 milliwatts and the non-inductive input does not require a coil suppression diode.

5. ***Insensitivity*** — Neither orientation, as with mercury wetted contacts, nor external magnetic fields affect the operation of PVRs. What's more, PVRs do not generate magnetic fields. Therefore, lack of magnetic "crosstalk" allows maximum packing density. Of course, PVR microelectronic power IC relays feature the very high shock and vibration resistance characteristic of solid state devices.

6. ***Size*** — At under 0.002 in.^{3} per pole, International Rectifier PVRs are considerably more compact than low thermal EMRs of equivalent performance. This allows great economy in board mounting area.

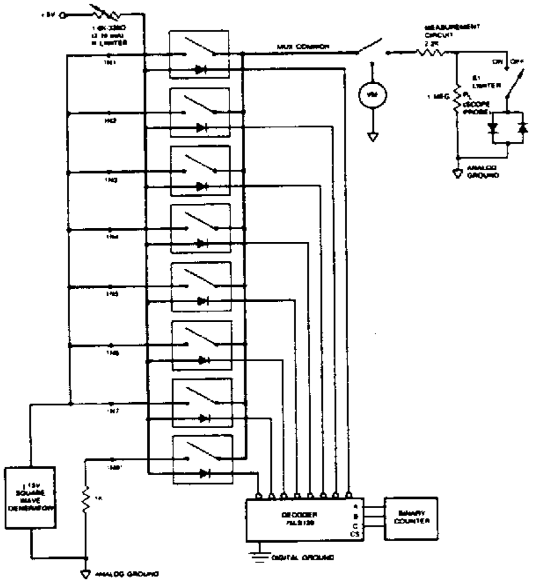
7. ***Analog Switch Comparison*** — Relative to solid state analog switches, PVRs have complete input isolation (up to 4000 VAC), high blocking voltage capability, much lower on-state resistance and are free of latch-up. Switches remain open when logic power is turned off. Signal sources remain separated without the precaution of disconnecting inputs or supplying short circuit protection.

Multiplexing Applications

Analog multiplexing requires an array of swtiches operating individually or in groups to connect each of several signal sources to a common amplifier or measurement system. If channels are selected in sequential order this device is sometimes referred to as a "scanner." A system capable of selection in random order is usually called a multiplexer. Figure 1 is an illustration of a low level differential multiplexer using 3 switch poles per channel to connect the signal and shield or guard to the measurement system; a high gain amplifier, sample/hold and A/D converter.

Many important performance characteristics can easily be demonstrated with a simple configuration shown in Figure 3a, an 8-channel single ended multiplexer using the PVA3354 as the switching element.

DC leakage through individual switches can be observed by turning off the logic drive power and connecting a 200V supply to the MUX common. A voltmeter with 10 meg input impedance connected between an input and analog ground will show the leakage current as the voltage drop across the 10 megohm input impedance. Inversely, connecting all inputs to a 200 volt signal and measuring the output on the MUX common yields the leakage through all eight switches. Typical measurement with this method shows about 2 nA or an average off resistance of 10^{11} Ohms per channel.



* CHANNEL UNDER TEST

Figure 3a. 8 Channel Multiplexer Test Circuit

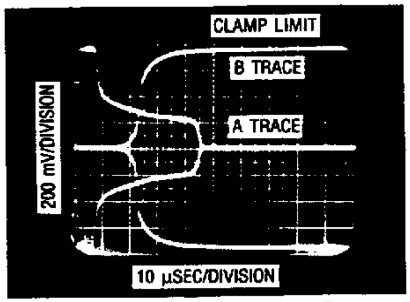


Figure 3b. Test Circuit Switching Characteristics. Test conditions use PVA3354 devices, approx. 1000 channels/sec, LED drive 5 mA, scope triggered on leading and trailing edge of drive pulse

With logic power applied, a binary counter and decoder sequentially scans all eight channels. Note that no delay is needed between successive addresses because of the "Break" before "make" operation of the PVA. The channel under test is connected to a 1K Ohm zero volt source. The seven remaining inputs are tied to the output of a 30 Vp-p square wave generator to demonstrate the effects of crosstalk and settling after extreme preconditions on the prior channel. By adjustment of the control current limiting resistor, the effect of varying control current on switching speed is apparent. The use of a square wave will also show the effects of crosstalk as a disturbance of the settled 0 voltage signal. Superimposed oscilloscope photos of the turn-on and turn-off of the channel under test are shown in Figure 3b. The pair of "A" traces display settling of the channel under test to 0 volts. The "B" traces show the turn-off with the selection of the next channel. On turn-on, a short delay occurs before the prior channel is disconnected from the MUX common. The MUX slowly drifts toward 0 until the channel under test begins to turn on and rapid settling occurs. On turn off, the short delay is experienced but the MUX common does not appear to move until the next channel begins to turn on. Note that full transition occurs in less than 50 microseconds. The traces of 3b are taken with the diode clamp circuit connected to prevent overloading the oscilloscope input.

The dependence of switching speed on control current is shown in Fig. 4. Switching speed of an order of magnitude faster than a high quality reed switch is readily obtained with a series 74LS driver. The turn-off delay remains nearly constant until the drive pulse width is too narrow to allow complete charging of the fast turn-off circuit, extending the delay before turn-off occurs. Charging may be made faster with greater control current or using an RC circuit to speed charging while limiting the steady state current to a nominal value.

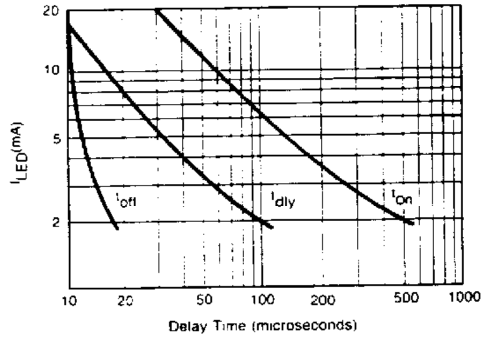


Figure 4a. Typical Delay Times

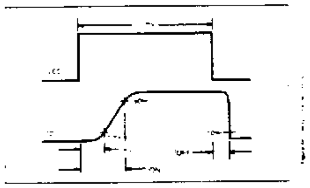


Figure 4b. Delay Time Definitions

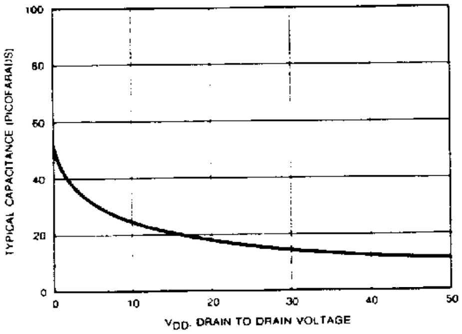


Figure 4c. Typical Output Capacitance

The closed circuit resistance of a PVA series device is greater than that of a metallic contact. A bidirectional 300 volt relay, e.g., the PVA3354, has a typical on-resistance of 20 Ohms. A 100 volt PVA1354 offers a 5 Ohm resistance. Comparable unidirectional 300 and 100 volt blocking relays, such as the PVD3354 and PVD1354 devices, reduce on-resistance by a factor of 4:1 or 5 and 1 Ohm respectively. While the resistance is significant it is stable and does not degrade with switching, allowing for compensation in the design or calibration of the system.

Multi-Level Multiplexing

The maximum voltage occurring across an open switch must be limited to less than the maximum blocking voltage or avalanche can occur. For example, if it is necessary to monitor signals on separate phases of the 120V AC line, a multi-level multiplexing scheme as shown in Figure 1 can be used to double the number of open switches between phases. This increases the maximum blocking voltage between groups to 600V.

To achieve a low on-resistance, a solid state switch requires a large area chip resulting in greater capacitance than a metallic contact and this must be considered in evaluating crosstalk for high frequency signals. Nonlinear open circuit capacitance of a PVA, shown in Figure 4c, varies from 50 to 10 pF with voltage. Larger signals or signals with DC bias reduce capacitance and result in less crosstalk.

Cascading through 2 switching levels also reduces crosstalk. For example, the worst case capacitive coupling for a 64 channel MUX is reduced by a ratio of 14/63 or -13 db over a single level multiplexer.

The "T" Switch

Certain applications may benefit from improved crosstalk rejection provided by the "T" switch illustrated in Figure 5a. By attenuating the capacitively coupled noise signal through shorting switch, S3, a much smaller error signal can pass through to the MUX output. The "T" switch should be considered where pulse or high frequencies are to be multiplexed. The equivalent circuit shown in Figure 5b may be used to calculate the worst case cross talk for the PVA3354 device.

Flying Capacitor Multiplexer

A flying capacitor multiplexer, shown in Figure 6, utilizes two pairs of switches per channel to isolate both signal and return from the measurement system. This type of MUX is usually applied to low level, low frequency inputs, e.g., therocouples with accompanying high common mode voltages. This technique offers excellent common mode rejection and isolation of the common mode source from the measurement system. A low pass filter, R1, R2, C1, is often used on the input. The flying capacitor, C2, is initially charged to the signal voltage through S1 and S2. Using metallic contacts, rapid charge transfer between capacitors results in contact pitting as the switches make initial contact. Resistors R3 and R4 are used to limit the peak current to extend the life of the contacts. A semiconductor switch does not suffer from pitting and can easily handle the transient current on switch closure, eliminating the need for resistors R3 and R4 and their resultant scaling error. The life of the PVA relay is therefore extended many times over that of a high quality reed switch.

Variations

Figure 7a illustrates applications of a PVA series microelectronic power IC relay to an analog integrator. S1 causes a reset by shorting the feedback capacitor. S2 and S3 vary the integration time constant.

Figure 7b illustrates an input selector which can be used to select or sum inputs to an operational amplifier.

High voltage signals can be attenuated in a manner necessary for accurate selection of multiple inputs as shown in Figure 7c. The 300 volt blocking capability of the PVA3354 allows a relative high ratio of R_2 and R_1, thereby minimizing any loading or interference effects between channels.

Solid State Conversion

International Rectifier's new microelectronic power IC relays, combining MOSFET outputs with photovoltaic isolation, are replacing electo-mechanical relays in many advanced multiplexer and instrument related designs. Although there are some limitations, such as open circuit capacitance and closed circuit resistance, the knowledgeable designer can overcome these difficulties and reap a large net benefit from the many inherent advantages of solid state performance.☐

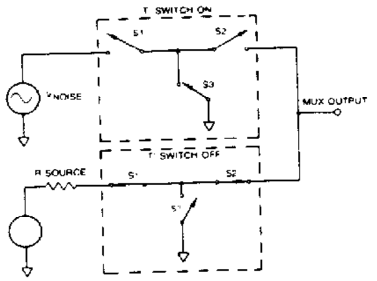


Figure 5a. Simplified Schematic of 'T' Switch MUX

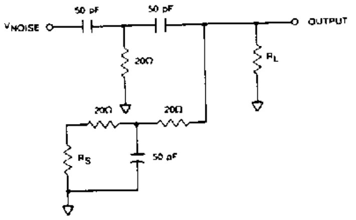


Figure 5b. Equivalent of 'T' Switch Circuit

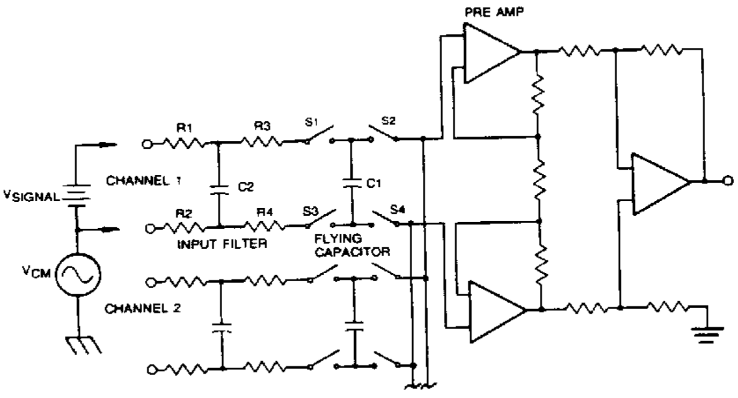


Figure 6. Flying Capacitor MUX

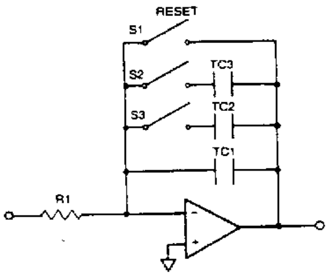


Figure 7a. Integrator Time Constant and Reset Selector

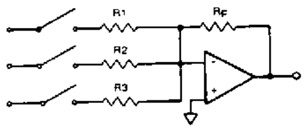


Figure 7b. Input Selector

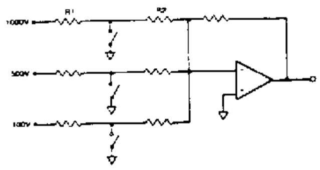


Figure 7c. High Voltage Selector